FLUID INJECTOR AND INJECTION METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. Application No. 10/242,341, filed September 12, 2002, which is hereby incorporated herein in its entirety by reference.

BACKGROUND OF THE INVENTION

This invention relates generally to apparatuses and methods for injecting fluids and more specifically to an injector and associated method for injecting combustion fluids into a combustion chamber.

2) Description of Related Art

The combustion of carbon-based compounds, or carbonaceous fuels, is widely used for generating kinetic and electrical power. In one typical electric generation system, a carbonaceous fuel such as natural gas is mixed with an oxidizer and combusted in a combustion device called a gas generator. The resulting combusted gas is discharged to, and used to rotate, a turbine, which is mechanically coupled to an electric generator. The combusted gas is then discharged to one or more additional combustion devices, called reheaters, where the combusted gas is mixed with additional fuel and/or oxidizer for subsequent combustion. The reheaters, which typically generate pressures lower than those found in the gas generator, discharge the reheated gas to one or more turbines, which are also coupled to the electric generator.

The combustion in the gas generator and reheaters results in high temperatures and pressures. In some low-emission systems, pure oxygen is used as the oxidizer to eliminate the production of nitric oxides (NOx) and sulfur oxides (SOx) that typically result from combustion with air. Combustion of carbonaceous gases with pure oxygen can generate combustion temperatures in excess of 5000° F. Such extreme conditions increase the stress on components in and around the combustion chambers, such as turbine blades and injectors. The stress increases the likelihood of failure and decreases the useful life of such components.

Injectors are used to inject the combustion components of fuel and oxidizer into the gas generator and the combusted gas, fuel, and/or oxidizer into the reheaters.

Because of their position proximate to the combustion chamber, the injectors are subjected to the extreme temperatures of the combustion chamber. The injectors may also be heated by the passage of preheated combustion components therethrough. Failure of the injectors due to the resulting thermal stress caused by overheating increases operating costs, increases the likelihood of machine downtime, and presents an increased danger of worker injury and equipment damage.

One proposed injector design incorporates a mixer for combining a coolant with the fuel before the fuel is combusted. For example, U.S. Patent No. 6,206,684 to Mueggenburg describes an injector assembly **10** that includes two mixers **30**, **80**. The first mixer **30** mixes an oxidizer with a fuel, and the second mixer **80** mixes coolant water with the prior mixed fuel and oxidizer. The mixture then flows through a face **121** to a combustion chamber **12** for combustion. The coolant water reduces the temperature of combustion of the fuel and, thus, the stress on system components. One danger presented by such a design is the possibility of "flash back," or the combustion flame advancing from the combustion chamber into the injector. Flash back is unlikely in an injector outlet that has a diameter smaller than the mixture's "quenching distance." Thus, flash back can be prevented by limiting the size of the injectors. Undesirably, however, a greater number of small injectors is required to maintain a specified flow rate of the combustion mixture. The increased number of injectors complicates the assembly. Small injectors are also typically less space-efficient because the small injectors require more space on the face than would a lesser number of large injectors that achieve the same flow rate. Space on the face is limited, so devoting more space to the injectors leaves less space for other uses, such as for mounting other components. The small injectors are also subject to further complications due to their size. For example, small passages and outlets in the injectors can become blocked by particulates present in the fuel, oxidizer, or coolant. Thus, the reactants must be carefully filtered before passing through the injector. Moreover, typical reheaters are not designed to accommodate liquids, so the coolant water cannot be used in them.

In another proposed oxygen-fed combustion cycle, the gas generator is eliminated and gaseous combustion components are provided for initial combustion in a gas turbine combustor. The gas turbine combustor, sometimes also called a reheater, is similar to the reheater of the conventional cycle described above in that all of the inputs are in gaseous form. Cooling is achieved by diluting the combustion

components with recirculated flue gas comprising steam and carbon dioxide. The flue gas dilutes the oxygen content in the combustion device and thus the combustion temperature. One such cycle, described as "Combined Cycle Fired with Oxygen," is discussed in "New Concepts for Natural Gas Fired Power Plants which Simplify the Recovery of Carbon Dioxide," by Bolland and Saether, Energy Conversion Management, Vol. 33, No. 5-8, pp. 467-475 (1992). Advantageously, this cycle effectively reduces combustion temperatures, and the elimination of the gas generator simplifies the system. No special turbines are required for receiving hot gases from a gas generator, and the gas turbine combustor can discharge to a turbine that is designed for use with a conventional reheater. However, the gas turbine combustor is incompatible with the injectors designed for conventional gas generators, which provide inadequate flow rates and do not provide recirculated gases to the combustion chamber. Further, injectors for gas generators are typically designed to operate at the higher operating pressures found in a gas generator and are inoperable or inefficient when used in a lower pressure gas turbine combustor or reheater. Nor is the gas turbine combustor compatible with injectors designed for conventional reheaters, because the gas turbine combustor requires a lower pressure drop across the injectors than that provided in conventional reheaters.

Moreover, as the availability and price of various combustion fuels change, it is sometimes desirable to change the type of combustion fuel that is used. However, because different combustion fuels have different characteristics, such as heating values, conventional injectors must be adjusted or replaced in order to provide efficient service with the different fuels. Thus, changing the type of fuel that is combusted in a system requires servicing the injectors and thereby interrupting service, reducing output, and increasing costs.

Thus, there exists a need for an apparatus and method for injecting fluid components of combustion into a combustion chamber of a combustion device. The apparatus and method should provide for injection of a recirculated gas to limit the temperature of the injector to decrease thermal stress, likelihood of failure, and operating costs. The injectors should be compatible with combustion devices that inject gaseous coolants, including reheaters, and should provide efficient injection and mixture of combustion gases of various types and heating values.

BRIEF SUMMARY OF THE INVENTION

The present invention provides an injector and an associated method for injecting and mixing gases, comprising a carbonaceous fuel and oxygen, into a combustion chamber of a combustion device. The injector may have an annular space proximate to its perimeter, through which a recycled mixture of steam and carbon dioxide can be injected to limit the combustion temperature, thereby decreasing thermal stress on components in and around the combustion chamber. Further, the injector has different jets, which can be used to separately inject different combustion fuels. Thus, the same injector can permit different combustion fuels to be alternatingly injected, each under the proper conditions. The injector is compatible with combustion devices that inject only gaseous fluids, including a reheater. The injector can be used in a reheater that recombusts a combusted gas that is discharged from a gas generator and turbine. Alternatively, the injectors can be used in a reheater that is the initial combustion device in a power generation cycle.

According to one aspect of the present invention, there is provided an injector for injecting combustion fluids into a combustion chamber. The injector includes an injector body that defines an injector face facing the combustion chamber, a main bore, and at least one main jet extending from the injector face to the main bore. A first plurality of fuel jets extend from the injector face and are fluidly connected to a first fuel inlet, typically by means of a first fuel manifold. Similarly, a second plurality of fuel jets extend from the injector face and are fluidly connected to a second fuel inlet, typically by means of a second fuel manifold. The central axis of each of the fuel jets defines a converging angle relative to one of the main jets such that fluid flowing from the fuel manifolds into the combustion chamber through the fuel jets impinges on a stream of fluid flowing from the respective main jet. The converging angle may be between about 10° and 45° such that convergence occurs in the combustion chamber. According to other aspects of the invention, a center of each of the main jets is located at least about 4 inches from the centers of the other main jets, and each of the main jets has a diameter of at least about 1 inch.

The main bore may be fluidly connected to a source of oxidizing fluid substantially free of nitrogen and sulfur, the first fuel manifold may be fluidly connected to a first source of fuel, including hydrogen and carbon monoxide, and the second fuel manifold may be fluidly connected to a second source of fuel, including

methane. Each of the first and second manifolds comprise an annular space that extends circumferentially around at least one of the main jets. In another embodiment, each of the second fuel jets may be smaller in cross sectional area than each of the first fuel jets. As such the fuel jets may be tailored to the delivery requirements necessary for the particular type of fuel to be injected via the fuel jets.

In one advantageous embodiment, the injector also includes a first sleeve that defines an interior space. The injector body is positioned in the interior space such that a first annular space is defined between the injector body and the first sleeve. In one aspect of the invention, the first annular space is fluidly connected to a source of a recycle gas comprising steam and carbon dioxide. In another aspect, the injector includes a recycle gas inlet and a second sleeve which defines a second annular space between the first and second sleeves. The first sleeve defines at least one first sleeve aperture fluidly connecting the first annular space to the second annular space, and the second sleeve defines at least one second sleeve aperture fluidly connecting the second annular space to the recycle gas inlet. In a further aspect, the injector includes a circumferential passage that extends along the perimeter of the second sleeve and fluidly connects the second annular space to the recycle gas inlet so that gas enters the recycle gas inlet and flows generally in a first direction in the second annular space and a second, generally opposite, direction in the first annular space. According to another aspect of the invention, the injector body also defines a coolant chamber that is configured to receive and circulate a coolant fluid.

The present invention also provides a method of injecting combustion fluids into a combustion chamber. At least one stream of oxidizing fluid, including oxygen and substantially free of nitrogen and sulfur, is injected into the combustion chamber. The oxidizing fluid may be injected in streams located with at least about 4 inches between their centers, and each stream may have a diameter of at least about 1 inch. A first combustion fuel and a second combustion fuel are alternatingly injected through fuel jets into the combustion chamber and impinged on the stream of oxidizing fluid. The fuel can be injected through a manifold defining an annular space that extends circumferentially around at least one of the main jets, and can be injected at a converging angle between about 10° and 45° relative to the stream of oxidizing fluid such that convergence occurs in the combustion chamber. The method also includes combusting the fuel with the oxygen. In one aspect of the present invention, a recycle gas including steam and carbon dioxide is injected into the

combustion chamber through a first annular space at an inside perimeter of the combustion chamber, for example, to limit the combustion temperature to about 4000° F. In another aspect, a coolant fluid is circulated through at least one coolant chamber in an injector body.

Thus, the present invention provides an injector and method for injecting combustion fluids, for example, into a gas generator or reheater, through a first and second plurality of fuel jets. Different combustion fluids can be injected through fuel jets and combusted efficiently, thereby increasing the versatility of the injector and decreasing the necessity of replacing or modifying the injector. Additionally, the injector and method limit the temperature of the injector and decrease the thermal stress on the components, thereby decreasing the likelihood of failure and the operating costs.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

Figure 1 is a partial cut-away isometric view of an injector according to the present invention;

Figure 2 is another partial cut-away isometric view of the injector of Figure 1;

Figure 3 is an elevation view of the injector of Figure 1;

Figure 4 is a partial cross-sectional view of the injector of Figure 3 as seen from line 4-4; and

Figure 5 is a schematic of a power generation cycle that is compatible with the injector of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

There is shown in Figure 1 an injector **10** according to the present invention, which is used to inject fluids into a combustion chamber **100**. The injector **10** has an injector body **14** with an injector face **12** that is oriented towards the combustion chamber **100**. The injector body **14** also includes a plurality of jets **20, 32, 52** that are fluidly connected to one or more inlets **18, 34, 54** as discussed further below. The fluids enter the injector body **14** through the inlets **18, 34, 54** and are injected into the combustion chamber through the jets **20, 32, 52**. A first sleeve **80**, which is generally shown as a hollow cylindrical tube, surrounds the injector body **14** and defines part of the combustion chamber **100**. A first annular space **82** is defined between the outside of the injector body **14** and the inside of the first sleeve **80**. A recycle gas inlet **84**, which is fluidly connected to the first annular space **82**, supplies a recycle gas through the annular space **82** to the inside perimeter of the first annular space **82** and the combustion chamber **100**.

The combustion that results in the combustion chamber **100** is a combustion of a fuel and oxygen. The fuel can be, for example, a carbonaceous gas such as methane, ethane, propane, or a mixture of hydrocarbons and may be derived from crude oil or a biomass fuel. Two advantageous carbonaceous fuels are methane and a synthesis gas, or syngas, which includes hydrogen and carbon monoxide. The carbonaceous fuel can be in liquid, gaseous, or combined phases. The oxygen is supplied in an oxidizing fluid. In one advantageous embodiment of the invention, the carbonaceous fuel and the oxygen are supplied in gaseous form and substantially free of nitrogen and sulfur. In the context of this patent, the phrase "substantially free of nitrogen and sulfur" indicates a combined content of less than 0.1 percent nitrogen and sulfur by weight and preferably less than 0.01 percent. Oxygen can be separated from atmospheric air according to methods known in the art and may include trace gases, such as argon.

The combustion of fuel and oxygen in the combustion chamber **100** generates a combusted gas and causes an increase in temperature and gas volume and a corresponding increase in pressure. The combusted gas is discharged to a power take-off device, such as a turbine, and useful energy is generated for use or storage. For example, the turbine can be coupled to an electric generator, which is rotated to generate electricity.

As shown in Figure 2, the oxidizing fluid is supplied through the main inlet **18** to a main bore **16** of the injector body **14**. The oxidizing fluid flows from the main bore **16** through the injector face **12** and into the combustion chamber **100** via a plurality of main jets **20**. Six main jets **20** are shown in the illustrated embodiment, but any number of jets **20** may be provided. The diameter of the main jets **20** is chosen so that predetermined flow rates of oxidizing fluid through the main jets **20** can be achieved by supplying the oxidizing fluid to the main inlet **18** at predetermined pressures higher than the pressure in the combustion chamber **100**. In one advantageous embodiment, each of the main jets **20** has a diameter at the injector face **12** of at least about 1 inch, and a center of each of the main jets **20** is at least about 4 inches from the centers of the other main jets **20**. The oxidizing fluid flows into the combustion chamber **100** as streams emitted from the main jets **20**, which, in the illustrated embodiment, are generally oriented parallel to a central axis that extends lengthwise through the main bore **16** of the injector body **14**.

A first fuel enters the first fuel inlet **34** and flows through a first fuel downcomer **38** to a first fuel manifold **30**. The first fuel manifold **30** is an interior space defined by the injector body **14** that fluidly connects the downcomer **38**, and hence the first fuel inlet **34**, to the first fuel jets **32**. As shown in Figures 2 and 4, the first fuel manifold **30** of the illustrated embodiment comprises both an annular chamber **42** that extends circumferentially around the main jets **18** and a central chamber **40** located central to the main jets **18**. The central chamber **40** and the annular chamber **42** are fluidly connected by tunnels (not shown) that are generally perpendicular to the main jets **18**. It is appreciated that there are numerous alternative configurations of the first fuel manifold **30**, the downcomer **38**, and the first fuel inlet **34** for fluidly connecting the first fuel source to the first fuel jets **34**.

The first fuel is discharged from the first fuel jets **32** into the combustion chamber **100**. In the illustrated embodiment, 24 first fuel jets are provided, with 4 located at spaced intervals around each of the main jets **20**, though any number of first

fuel jets **32** can be provided. Each of the first fuel jets **32** is configured such that a central axis of each first fuel jet **32** converges with a central axis of the respective main jet **20** in the combustion chamber **100** so that fuel discharged from the first fuel jets **32** impinges on the stream of oxidizing fluid flowing from the respective main jet **20**.

Similar to the first fuel, a second fuel enters the second fuel inlet **54** and flows through a second fuel downcomer (not shown) to a second fuel manifold **50**. The second fuel manifold **50** is an interior space defined by the injector body **14** that fluidly connects the second fuel downcomer, and hence the second fuel inlet **54**, to the second fuel jets **52**. As shown in Figure 4, the second fuel manifold **50** of the illustrated embodiment comprises 6 annular chambers, each extending circumferentially around one of the main jets **20**. The annular chambers are fluidly connected to one another by tunnels (not shown) that extend in a direction generally perpendicular to the main jets **20**. In the illustrated embodiment, 24 second fuel jets are provided, with 4 located at spaced intervals around each of the main jets **20**. Each of the second fuel jets **52** is also configured such that a central axis of each second fuel jet **52** converges with the central axis of the respective main jet **20** in the combustion chamber **100** so that fuel discharged from each of the second fuel jets **52** into the combustion chamber **100** impinges on the stream of oxidizing fluid flowing from the respective main jet **20**.

The converging angle between each of the fuel jets **32**, **52** and the respective main jet **20** affects the extent to which the fuel is mixed with the oxidizing fluid as well as the location in the combustion chamber **100** at which the fuel and oxidizing fluid are sufficiently mixed for combustion to occur. The distance between each of the fuel jets **32**, **52** and the respective main jet **20** also affects the mixing of the fuel and oxidizing fluid. If the mixing and the combustion of the fuel and oxidizing fluid occur close to the injector face **12**, the injector face **12** and the injector **10** may be more subject to the heat generated by the combustion and require additional cooling. In one advantageous embodiment of the present invention, each of the first and second fuel jets **32**, **52** defines a converging angle relative to one of the main jets **20** of between about 10° and 45°. In another embodiment, the fuel jets are configured such that fuel flowing from the fuel jets **32**, **52** impinges on the stream of oxidizing fluid flowing from the respective main jet **20** in a region located within about 2 inches of the injector face **12**. Thus, the fuel that is discharged through the jets **32**, **52** mixes

with the oxidizing fluid and facilitates a uniform combustion of the fuel. However, the fuel is not mixed and combusted so close to the jets **20, 32, 52** that the combustion occurs in the injector **10**.

The arrangement of the first and second fuel jets **32, 52** is shown in Figure 3. It is appreciated that any number of first and second fuel jets **32, 52** can be provided, including a single first and second jet **32, 52** for each main jet **20**. Preferably, the first and second jets **32, 52** are arranged symmetrically about the main jets **20**, but asymmetric arrangements are also possible. Also, while jets **32, 52** in the illustrations have a round cross section, other shapes are also possible. For example, one or both of the first and second fuel jets **32, 52** can be a single jet that defines a slot extending circumferentially around all or part of the main jets **20**. Further, Figure 3 illustrates the difference in cross-sectional size between the first fuel jets **32** and the second fuel jets **52**. Although any size of jets **32, 52** can be used, the size of the jets **32, 52** preferably is chosen in consideration of the heating value of the fuels, the operating pressure, and the number of jets **32, 52**. For example, the diameters of the jets **32, 52** can be calculated according to the required mass flow rate of fuel for the desired combustion and the necessary momentum of the fuel into the combustion chamber **100** for proper mixing with the oxidizing fluid. The required mass flow rate of different fuels may vary according to the heating values of the fuels, though it may be desirable to inject the different fuels with similar momentum to ensure proper mixing of each fuel with the oxidizing fluid. Thus, the differently sized jets **32, 52** allow the use of different fuels while still maintaining the same rate of heat generation and the same momentums of the fuels. For example, in the embodiment shown in Figure 3, the first fuel jets **32** are approximately three times the diameter of the second fuel jets **52**. Thus, if the first fuel jets **32** are used for a first fuel that has a heating value of approximately one-third of the heating value of the second fuel, the amount of heat generated by the two fuels will be similar if the two fuels have equivalent densities and are injected at similar momentums.

The relative sizes of the injector **10** and jets **20, 32, 52** are also shown in Figure 3. In one embodiment, the diameter of the injector **10** is about 12.5 inches wide, and the diameters of the fuel jets **32, 52** are at least about 0.1 inch. The main jets **20** are about one inch in diameter at the injector face **12**, and a center of each of the main jets **20** is at least about 4 inches from the centers of the other main jets **20**.

In one advantageous embodiment, the second fuel jets **52** are used to inject natural gas, which is approximately 90 percent methane. The first fuel jets **32** are used to inject a synthesis comprising carbon monoxide, hydrogen, and carbon dioxide. The synthesis gas can be generated by using steam and oxygen for the gasification of petcoke, which is about 90 percent solid carbon by weight, moisture, and ash. The first fuel and the second fuel can be injected simultaneously, but according to one advantageous embodiment of the present invention, only one of the first and second gases is injected at a time. Thus, fuel gas that is used for combustion can be changed without changing the injector **10** and can be chosen according to other criteria such as availability, price, and efficiency. Additionally, it is understood that additional jets can be provided to further improve the versatility of the injector **10**. For example, the injector **10** can include a third set of fuel jets (not shown) with a corresponding fuel manifold and inlet, thus allowing a third fuel source to be independently supplied to the combustion chamber **100**. The configuration of each of the first and second plurality of fuel jets **32**, **52**, and any additional fuel jets, can be tailored to inject a particular type of gas under particular conditions. For example, the number and size of the first fuel jets **32** and the spacing and angle between the first jets **32** and the main jets **20** can be tailored specifically for the injection of a particular fuel through the first jets **32**, for example, a synthesis gas comprising hydrogen and carbon monoxide. Similarly, the second fuel jets **52**, and any additional sets of fuel jets, can be configured for other fuels such as methane or natural gas.

As shown in Figures 1 and 2, a second sleeve **90** circumferentially surrounds the first sleeve **80**, defining a second annular space **94** between the two sleeves **80**, **90**. The second annular space **94** is fluidly connected to a circumferential passage **86**, which extends around the second sleeve **90**, and to a diluent gas inlet **84**. The diluent gas inlet **84** is fluidly connected to a source of diluent gas (not shown). Thus, the diluent gas enters the diluent gas inlet **84** and flows through the circumferential passage **86** and into the second annular space **94** through the second sleeve apertures **92**. The diluent gas flows through the second annular space **94** in a direction that is generally opposite to the direction of the oxidizing fluid and the fuel in the jets **20**, **32**, **52**. From the second annular space **94**, the diluent gas flows through a plurality of first sleeve apertures **88** that fluidly connect the second annular space **94** and the first annular space **82**. Once in the first annular space **82**, the diluent gas reverses its direction of flow and flows toward the combustion chamber **100**, where it is then

mixed with and becomes part of the combustion gas in the combustion chamber **100**. The diluent gas dilutes the combustion gas and moderates the temperature of the combustion. Although liquid diluents can also be used, a gaseous diluent is preferred. Various diluent gases can be used including, in one advantageous embodiment, a recycle gas from a turbine in which the combustion gas from the combustion chamber **100** is expanded. The recycle gas comprises steam and carbon dioxide. The degree of cooling that is provided by the recycle gas depends on the combustion temperature, the flow rate of the gases into the combustion chamber **100**, the temperature of the recycle gas, and the composition of the recycle gas. Preferably, the temperature in the combustion chamber **100** is reduced to at least about 4000° F, and most preferably to about 2000° F.

The injector **10** can also be cooled by a coolant fluid such as water that flows through a coolant chamber (not shown). The coolant chamber is an interior gap defined by the injector body **10**, which is fluidly connected to a coolant inlet **72** and a coolant outlet **74**. Coolant fluid is pumped into the coolant inlet **72** and discharged from the coolant outlet **74**. It will be appreciated that various configurations of coolant chambers can be used as are known in the art.

In one advantageous embodiment of the present invention, the injector **10** is used to inject gases into a combustion chamber **100** that is compatible only with gases. For example, the injector **10** can be used to inject a carbonaceous gas, gaseous oxygen, and a mixture of steam and carbon dioxide into a reheater that is used to combust gases in an electricity generation plant. The reheater can recombust an exhaust gas that is discharged from a gas generator and turbine, as discussed in U.S. Patent Application No. [...], titled "LOW-EMISSION, STAGED-COMBUSTION POWER GENERATION," filed concurrently herewith and the entirety of which is incorporated herein by reference. Alternatively, the reheater can be the initial combustion device in a power generation cycle as shown, for example, in Figure 5.

The power generation cycle shown in Figure 5 includes a reheater **140** that receives oxygen and a carbonaceous gas, for example, a synthesis gas, for combustion. The oxygen is generated in an air separation unit **110**, which removes at least most of the nitrogen from the air and discharges the oxygen substantially free of nitrogen and sulfur. The nitrogen can be removed using a cryogenic process, as will be understood by one of ordinary skill in the art. In that case, the cryogenic nitrogen that is derived from the process can be sold or used in subsequent cooling processes in

the power generation cycle. In other embodiments, the oxidizing fluid can be derived from sources other than the air separation unit **110**, for example, from a storage tank, delivery pipeline, or other oxygen generation apparatuses that are known in the art.

In the illustrated embodiment of Figure 5, the synthesis gas, or syngas, is generated in a syngas generator **120**. The syngas generator **120** is shown for illustrative purposes only, and it is understood that syngas can be obtained by other processes known in the art. Further, combustion gases other than syngas can be used. For example, the combustion gas can comprise methane, ethane, propane, or a mixture of hydrocarbons and may be derived from crude oil or a biomass fuel.

The oxidizing fluid is compressed by compressors **112, 114** and delivered to the reheater **140** and the syngas generator **120**. The syngas generator **120** includes a gasifier **126** that also receives water and petroleum coke, or petcoke, from water and petcoke sources **122, 124**. The petcoke is gasified in the gasifier **126** to form an exhaust gas that includes the syngas, as known in the art. The syngas comprises hydrogen, carbon monoxide, and carbon dioxide, and in this embodiment specifically comprises about 50 percent carbon monoxide, 34.2 percent hydrogen, and 15.8 percent carbon dioxide. The syngas is passed through a high temperature heat recoverer **128** and a low temperature heat recoverer **130**, both of which are thermally coupled to a heat recovery steam generator **150**, described below.

The syngas is then discharged to the reheater **140**. The syngas enters the reheater **140** through the injectors **10**, as do the oxygen and a diluent. The diluent is a recycle gas that includes steam and carbon dioxide. The diluent dilutes the oxygen in the reheater, limiting the temperature in the reheater **140**. The product gas is combusted in the combustion chamber **100** of the reheater **140** to form a combusted gas or combustion product, which is discharged to a primary turbine **142**. The combustion product is expanded in the primary turbine **142** and energy is generated by rotating an electric generator **146** that is mechanically or hydraulically coupled to the primary turbine **142**. The combustion product from the primary turbine **142** is discharged to the heat recovery steam generator **150** where the combustion product is cooled. The heat recovery steam generator **150** acts as a heat exchanger by using thermal energy of the combustion product discharged from the primary turbine **142** to heat an intermediate exhaust gas from the high temperature heat recoverer **128**. The intermediate exhaust gas is then discharged to a first turbine **160**. The intermediate exhaust gas is discharged from the first turbine **160** to the heat recovery steam

generator **150** where it is reheated and discharged to a second turbine **162** and then a third turbine **164**. The intermediate exhaust gas is expanded in the turbines **160, 162, 164**, and the temperature and pressure of the intermediate exhaust gas are decreased. The operating pressures of the turbines **160, 162, 164** decrease consecutively so that the second turbine **162** operates at a pressure that is lower than that of the first turbine **160** and higher than that of the third turbine **164**. The turbines **160, 162, 164** are coupled to an electric generator **166**, which is rotated by the turbines **160, 162, 164** and generates electricity. Subsequently, the intermediate exhaust gas is discharged to a condenser **168** and a pump **170**, which returns the condensed exhaust to the syngas generator **120**.

The combustion product is cooled in the heat recovery steam generator **150**. A first portion of the combustion product is recycled from the heat recovery steam generator **150** to a compressor **144**, which compresses the combustion product and discharges the combustion product as the diluent to the reheater **140**. Bleed lines **148** connect the compressor **144** to the primary turbine **142**. The compressor **144** can be driven by a shaft that also couples the primary turbine **142** to the electric generator **146**. Although not shown, a single drive shaft may be driven by all of the turbines **142, 160, 162, 164**, and the same shaft may also drive the compressor **144**. In the embodiment of Figure 5, the diluent comprises approximately 67 percent steam and 33 percent carbon dioxide, though the actual proportions can vary.

A second portion of the combustion product is discharged to a high pressure compressor **172** where it is compressed to liquefy the carbon dioxide in the combustion product. The carbon dioxide is then discharged via a carbon dioxide outlet **174** and water is discharged through a water outlet **176**. The carbon dioxide and water may be recycled for use in other parts of the generation cycle or discharged.

Many modifications and other embodiments of the invention will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.